7.0 DISCHARGE TO SURFACE WATERS

In this chapter, the potential risks associated with discharge of treated municipal wastewater into surface-water bodies are evaluated for South Florida.

7.1 Definition of Discharge to Surface Waters

In South Florida, treated wastewater managed by this option is discharged into canals, creeks, and estuaries. At a minimum, wastewater discharged to surface waters must receive secondary treatment with basic disinfection. However, wastewater discharged to some water bodies (for example, Tampa Bay, Indian River Lagoon) must first receive advanced treatment, including nutrient removal.

Florida's Anti-Degradation Policy, which prohibits surface-water resources from being degraded, discourages discharge to surface waters because of the high cost of treatment and the ecological risks, which are generally perceived as high. Even treatment plants that use this option generally do so infrequently, as a backup when other options (for example, reuse) are not available.

7.2 Use of Discharge-to-Surface-Waters Option in South Florida

The discharge-to-surface-waters option is used to varying degrees throughout South Florida. As described in Chapter 2, Figure 2-2, facilities in Brevard, Hillsborough, and Sarasota counties make significant use of this option. Facilities in Hillsborough County rely on this option (roughly 75% of total design capacity) to a greater extent than do facilities in most other counties in South Florida. In Pinellas and Collier counties, treatment facilities use a combination of options, including discharge to surface waters. In Collier County, discharge to surface waters accounts for an insignificant portion (1%) of the total design capacity. Facilities in Broward, Palm Beach, and Dade counties rely primarily upon ocean outfalls and underground injection and do not discharge to surface-water bodies (see Figure 2-2).

The treatment facilities reviewed in this study that discharge to surface waters either discharge directly to estuaries with brackish water, coastal embayments, or to freshwater creeks or canals that eventually discharge to embayments. In Brevard County, the South Beaches and Cape Canaveral wastewater treatment facilities discharge to the Indian River Lagoon only when no other practical alternative exists. The Indian River Lagoon System and Basin Act of 1990, contained in Chapter 90-262, Laws of Florida, "prohibits new discharges or increased loadings from domestic wastewater treatment facilities into surface waters…." (FDEP, 2002a). Exceptions are made if the applicant can meet the following conditions:

- The permit applicant conclusively demonstrates that no other practical alternative exists and that the discharge will be treated to advanced treatment levels or higher

- The applicant conclusively demonstrates that the discharge will not cause or contribute to water-quality violations and will not hinder efforts to restore water quality in the Indian River Lagoon System
- The discharge is an intermittent discharge to surface waters occurring during wet weather conditions, subject to the requirements of applicable Florida Department of Environmental Protection (DEP) rules.

The Act also requires facilities to investigate the feasibility of using reclaimed water to promote reuse and reduce nutrient loadings. Based on these requirements, the Cape Canaveral treatment plant was upgraded in the mid-1990s to provide advanced wastewater treatment (AWT). The new AWT plant is part of a reclaimed water system that supplements the City of Cocoa Beach's reclaimed water supply. Discharge to the Banana River, a segment of the Indian River Lagoon, is allowed during periods of wet weather or when demand for reclaimed water is low (FDEP, 20021; Cape Canaveral Wastewater Treatment facility, personal communication).

In Hillsborough County, the Howard F. Curren AWT plant serves the city of Tampa. In 2000, the plant managed 48.5 million gallons per day (mgd) using a combination of discharges to Hillsborough Bay (a portion of Tampa Bay) and reuse of reclaimed water for cooling and irrigation (City of Tampa, Florida, 2001). In Sarasota County, the Gulfgate and Southgate treatment plants discharge into two freshwater creeks, Phillippi Creek and Methany Creek. These eventually drain to Roberts Bay (Marella, 1999). Gulfgate has a permit capacity of 1.80 mgd and no reuse capacity. Southgate has a permit capacity of 1.36 mgd and very limited reuse capacity. Both facilities discharge approximately 70% to 80% of their permitted capacity, and each is planning for expanded reuse (Joseph Squitieri, Florida Southwest DEP, personal communication).

7.3 Environment Into Which Treated Wastewater Is Discharged

7.3.1 Estuarine Environments

An estuary is defined as "a semi-enclosed coastal body of water that is connected to the sea and within which seawater is measurably diluted with fresh water from land drainage" (Pritchard, 1967). Estuaries are some of the most productive, diverse, and complex ecosystems on earth. They exhibit tremendous temporal and spatial variability in their physical, chemical, and biological characteristics.

Lagoons are considered a type of estuary. They are produced by wave action and are typically found behind a barrier beach or spit. Lagoons are characterized as being less well drained and are uniformly shallow, often less than 2 meters deep. Physical processes of mixing and circulation in lagoons are mostly wind-dominated, whereas freshwater inflow (from surface water and groundwater) tends to drive mixing and circulation in salt-marsh estuaries.

The Tampa, Sarasota, and Florida bays are representative of estuarine coastal embayments in South Florida. The Indian River Lagoon is an example of a lagoon system. Tampa Bay, Sarasota Bay, and Indian River Lagoon each receive effluent discharges treated to AWT standards. Although Florida Bay does not receive known or permitted discharges of treated wastewater, there are a number of relevant concerns regarding its water quality and aquatic habitat. These concerns establish a useful context in which to consider risks associated with the discharge-to-surface-waters option.

Potential human health and ecological risks associated with discharges to these environments would be greatly influenced by site-specific flushing rates and the depths of water bodies.

7.3.1.1 Tampa Bay

Tampa Bay is located on the west coast of the Florida peninsula and is part of the Gulf of Mexico. This extremely shallow bay (average depth of 4 meters) is the largest open-water estuary in Florida, encompassing over 400 square miles and with over 100 freshwater tributaries (Pribble et al., 1999). Dominant habitats in the Tampa Bay estuary include sea-grass beds, mangrove forests, salt marshes, and oyster bars. Wildlife is abundant; over 40,000 breeding pairs of birds, such as the brown pelican and roseate spoonbill, nest in Tampa Bay every year. The bay is also home to dolphins, sea turtles, and manatees.

Tampa Bay was heavily polluted before 1979. This pollution largely resulted from discharges of primary-treated wastewater from the Hooker's Point Wastewater Treatment Facility (now the Howard F. Curren Plant) into Hillsborough Bay, a subembayment of Tampa Bay. Since the state of Florida began requiring advanced treatment to remove nitrogen, the bay has been recovering. Water clarity and the health of benthic communities have improved, and sea grasses have reappeared (City of Tampa Bay Study Group, 2001a, 2001b). While the adverse effects of discharged wastewater have been reduced, the bay is still suffering from other pollution sources, particularly atmospheric and nonpoint source loading of nutrients. Sediment quality in Hillsborough Bay remains impaired; 33% of sediments are of marginal quality with respect to metals, and 8% of sediments are of poorer quality (Pribble et al., 1999).

7.3.1.2 Sarasota Bay

Sarasota Bay, located on the Gulf of Mexico in southwest Florida, is another coastal embayment that receives discharges of treated municipal wastewater. The bay is composed of two major embayments, Sarasota Bay and Little Sarasota Bay, and many smaller embayments. The bay is 56 miles long and ranges in width from 300 feet to 4.5 miles. Average depth throughout much of the bay ranges from 8 to 10 feet (Roat and Alderson, 1990). Sarasota Bay exhibits wildlife and habitat that are very similar to Tampa Bay, including mangroves, sea grasses, marine mammals, and waterfowl.

Since 1990, nitrogen discharges from wastewater treatment plants have been reduced by 80% because of the implementation of AWT and reuse programs (Sarasota Bay National Estuary Program, 1993). As a result, water quality and habitat quality have improved.

Sea-grass coverage in the bay has increased by 18% since 1988 (Sarasota Bay National Estuary Program, 2000).

7.3.1.3 Indian River Lagoon

The Indian River Lagoon is located on the east coast of Florida, stretching 156 miles from Ponce de Leon Inlet, south of Daytona Beach, to Jupiter Inlet near West Palm Beach (Adams et al., 1996). The Indian River Lagoon is a lagoonal estuary composed of several water bodies, including the Indian River, the Banana River, and Mosquito Lagoon. The lagoon system receives inputs of salt water via inlets from the ocean. Fresh water is received in the form of direct precipitation, groundwater seepage, surface runoff (discharges from creeks, streams, and drainage systems), and point sources such as wastewater treatment plants. The long narrow shape and shallow waters of the lagoon result in sluggish circulation patterns in many places. Circulation is primarily wind-driven, and tidal exchange is limited to six widely separated inlets with restricted tidal flushing (Adams et al., 1996).

In some areas, habitat loss and alteration have been significant. Portions of the Banana, North Indian, and South Indian rivers have experienced the greatest long-term declines in sea-grass cover within the lagoon system (Adams et al., 1996). Approximately 27% of the mangrove acreage in the Fort Pierce area was lost between 1940 and 1987 (Hoffman and Haddad, 1998). Many salt marshes and mangrove swamps were impounded and flooded to control mosquito breeding.

7.3.1.4 Florida Bay

Florida Bay is located at the southernmost tip of Florida, bounded by the mainland and the Keys. It is a semi-enclosed, shallow, oligotrophic bay, with depths ranging from 6 to 30 feet. The watershed, which discharges to the bay, includes all of the freshwater wetlands south of Lake Okeechobee. This vast area slopes gently and drains towards Florida Bay and the Gulf of Mexico (NOAA, 1999).

Although there are no known discharges to surface waters of municipal wastewater into Florida Bay, conditions in Florida Bay provide examples of many of the natural resource issues confronting wastewater and water managers in South Florida. The Florida Bay hydrologic system has been highly altered, largely through the construction of a complex canal and levee system to control flooding and provide fresh water for agriculture. The U.S. Geological Service (USGS) has been investigating environmental changes that have occurred over the past 150 years within Florida Bay and the surrounding South Florida ecosystem (McPherson et al., 2000; McPherson and Halley, 1996). Recent studies (Boyer et al., 1997, Brewster-Wingard and Ishman, 1999; Brewster-Wingard et al., 1996) have focused on describing temporal and spatial variability within the bay ecosystem. These studies show the following:

- Salinity in the bay has increased since the 1950s

- Before 1940, fluctuations in salinity and sea-grass distribution matched a natural cycle; since 1940, fluctuations have been greater and no longer match a natural cycle
- Sea grass and macrobenthic algae were much less abundant in the 1800s (and early 1900s) and have increased in the last half of the 20th century
- Invasive plants (for example, cattails) have increased in number and are slowly displacing the native saw grass communities along the canals that form part of the drainage system to Florida Bay
- Regional ecosystem disturbances occurring in the late 20th century have been accelerated by human activities
- Between 1991 and 1994, in the central region, nitrate, ammonia, and chlorophyll *a* increased
- Over the past 7 years, concentrations of phosphate and total phosphorus decreased dramatically throughout the bay
- The bay is becoming more phosphorus-limited from west to east.

In recent times, the bay has experienced sea grass die-offs, algal blooms, and declines in the populations of shellfish and sponges (USGS, 1996a). In western Florida Bay, a massive sea grass die-off began in 1987. Since then, some recovery of sea grasses has occurred, while other areas have been slow to revegetate. Algal blooms have been reported in the last few years across western Florida Bay, extending to the Florida Keys (NOAA, 1999).

7.3.2 Freshwater Environments

Much of the information that informs this analysis of the discharge-to-surface-waters option was obtained from treatment facilities located in Brevard, Hillsborough, and Sarasota counties. These facilities discharge directly to estuaries or to creeks or canals that discharge to an estuarine environment. This study did not reveal any effluent discharges to freshwater lakes or ponds in South Florida.

Florida's surface-water features include extensive wetlands and numerous lakes, streams, and canals. Streams and wetlands in South Florida have direct hydrologic connections to the surficial aquifer (Randazzo and Jones, 1997). Much of South Florida was originally covered with wetlands. Canals, which are a prominent surface-water feature in South Florida, were dug to drain these wetlands and make the land useable. Canals are the major surface-water drainage feature in South Florida outside of the Everglades (Englehardt et al., 2001). Many canals that receive effluent discharges subsequently empty into saltwater bodies.

Canals are generally man-made waterways or artificially improved rivers; they serve various uses such as irrigation, shipping, recreation, and flood control (Kapadia and Swain, 1996). They vary in size from a few feet wide and deep, to several hundred feet wide and 12 to 15 feet deep. Some canal banks are earthen, while others are encased in concrete.

Surface-water quality throughout large areas of South Florida has already been degraded by human activities, as summarized in two USGS reports on the National Water Quality Assessment (NAWQA) Program Study of South Florida. The USGS made several major findings concerning surface-water quality in South Florida (McPherson et al., 2000; McPherson and Halley, 1996):

- Concentrations of total phosphorus at NAWQA sites in South Florida exceeded the Environmental Protection Agency's (EPA's) Everglades water-quality standard of 0.01 milligram per liter (mg/L) and were above Everglades background levels. A major source of the phosphorus is fertilizer from agriculture.
- Dissolved organic carbon (DOC) concentrations were relatively high when compared with those in other waters of the United States. High DOC concentrations provide food for microorganisms to grow, reduce light penetration in water, and enhance transport and cycling of pesticides and trace elements, such as mercury.
- Pesticides were detected in almost all South Florida NAWQA samples. Most concentrations were below aquatic-life criteria, but the criteria do not address cumulative effects of mixtures of pesticides or their degradation products, which were common in the samples. Organochlorine pesticides, such as DDT and its degradation products, are still prevalent in bottom sediment and fish tissue at South Florida NAWQA sites, even though use of these pesticides has been discontinued in recent decades.
- Exotic plants and animals pose a threat to native biota, and herbicides that were used to control exotic plants were detected in surface water at NAWQA sites.
- Of 21 NAWQA areas nationwide, the Everglades has the second highest enrichment of methylmercury relative to mercury in sediments; methylmercury is highly biologically active and can be taken up by biota.
- The frequency of external anomalies (lesions, ulcers, and tumors) on fish collected at two NAWQA sites in South Florida places these sites among the top 25% of 144 NAWQA sites sampled nationwide. Such anomalies may indicate that fish are stressed by contamination.

The NAWQA study found that major causes for degradation of surface-water quality include modification of drainage patterns, wetland destruction, runoff from agricultural and urban areas, high concentrations of DOC and its effects on mercury transport and light transmission, and release of exotic species.

The USGS also collected water-quality samples between 1996 and 1997 within selected southeast canals that show increases in nutrient concentration corresponding to patterns of land use. For example, nitrate concentrations were highest in agricultural areas; ammonia and total and inorganic phosphorus concentrations were highest in urban areas; total organic nitrogen was highest in wetlands (Lietz, 2000).

In summary, surface-water quality in South Florida shows significant degradation as an apparent result of urban and agricultural activities. Canals in areas of urban and agricultural land use commonly contain water with high concentrations of nutrients, coliform bacteria, metals, and organic compounds when compared to water taken from areas that are remote from these canals. Wildlife has been stressed by human alteration of the hydrologic regime and by the addition of nutrients, sediment, and other pollutants to surface-water bodies (McPherson et al., 2000; McPherson and Halley, 1996).

7.4 Option-Specific Regulations and Requirements

This section describes regulations concerning treatment and discharge of wastewater to surface-water environments.

7.4.1 Treatment and Disinfection Requirements

At a minimum, treatment prior to discharge to surface water must include secondary treatment with basic disinfection (Florida Administrative Code [FAC] 62-600.510(1)). When discharges to surface waters is used as a backup to reuse systems, wastewater is frequently treated to reclaimed-water standards before being discharged. Discharge to Class I drinking waters requires principal treatment, which consists of secondary treatment and high-level disinfection (see Chapter 2). Discharge to waters contiguous to Class I waters requires review of the travel time of effluent to the drinking-water intake; the discharge must also meet Technology Based Effluent Limits (TBEL) or Water Quality Based Effluent Limits (WBEL), as established by the permit. The Florida DEP may require that a facility meet additional water-quality-based effluent limits; these provide and enforce more stringent requirements for effluent quality. TBELs and WBELs are based on the characteristics of the discharge, the receiving-water characteristics, and the criteria and standards of FAC 62-302.

Effluent discharge must not exceed 10 mg/L total nitrogen (FAC 62-600.420(2)(a)(2)), and effluent must contain maximum pollutant levels less than those specified for community water systems in FAC 62-550. These facilities must be designed to reduce total suspended solids to 5.0 mg/L or less before the application of disinfectant (FAC 62-600.540(5)(e)).

In order to be permitted to discharge to either Tampa Bay or the Indian River Lagoon, wastewater treatment plants must treat using AWT. Typically, AWT includes secondary treatment, basic disinfection, nutrient removal (nitrification, denitrification, and phosphorus removal), additional removal of metals and organic compounds, and filtration. Dechlorination is also required (see Appendix Table 1-1). AWT standards must be met on an average annual basis. AWT standards are summarized as follows:

- Carbonaceous biological oxygen demand ($CBOD_5$) must be less than 5 mg/L
- Total suspended solids must be less than 5 mg/L
- Total nitrogen (as N) must be less than 3 mg/L
- Total phosphorus (as P) must be less than 1 mg/L
- Discharge to a treatment or receiving wetland may not exceed 2 mg/L total ammonia (as N) on a monthly average.

Some treatment plants utilize wetland treatment before discharge into surface-water bodies; this provides further reductions in nutrient concentrations prior to discharge.

Basic disinfection (no more than 200 fecal coliform colonies per 100 milliliters (mL)) is a minimum requirement for all discharges to surface waters in Florida. High-level disinfection (fecal coliform removal below detectable limits per 100 mL) is required of all facilities discharging to Class I surface waters. Intermediate-level disinfection may be allowed, if discharge is to wetlands with restricted public access (FAC 62-600.440(5)g) or to surface waters that serve as backup to a reuse system and provided that there is no discharge to Class I waters or their tributaries (FAC 62-600.440(5)(h)). Dechlorination of chlorinated wastewater before discharge to surface waters is also required (see Tables 2-4 and 2-5).

Currently, there are no federal or state limits for concentrations of the pathogens *Giardia lamblia* or *Cryptosporidium* in treated wastewater. However, on January 1, 2002, the EPA did establish drinking-water treatment requirements for these pathogenic microorganisms. The EPA mandated drinking-water treatment to remove 99.9% of *Giardia lamblia* and 99% of *Cryptosporidium* from raw water sources (National Primary Drinking Water Standards, CFR 141). Florida DEP applies a numerical standard (no more than 5.8 cysts or oocysts per 100 L, which corresponds to a 1 in 10^{-4} human illness risk) for *Cryptosporidium* and no more than 1.4 cysts per 100 L for *Giardia* in reclaimed water (York et al., 2002). These recommended limits address the significant human health risks that may be associated with ingestion of viable pathogenic protozoans present in unfiltered or inadequately filtered treated wastewater.

7.4.2 Standards for Surface-Water Quality

In addition to discharge standards, Florida has use and classification standards for surface-water bodies (FAC 62-302.530). The standards are meant to protect the designated use of the water bodies. Table 7-1 summarizes the uses and criteria for some of the relevant stressors reviewed in this study (FAC 62-302.530).

Table 7-1. Criteria for Surface-Water Quality Classifications

Parameter	Units	Class I: Potable-Water Supply	Class II: Shellfish Propagation or Harvesting	Class III: Recreation, Propagation, and Maintenance of a Healthy Well-Balanced Population of Fish and Wildlife	
				Fresh	***Marine***
Fecal coliform bacteria	Numbers per 100 mL	MPN or MF counts cannot exceed monthly average of 200, nor exceed 400 in 10% of samples, nor exceed 800 on any day. Monthly averages must be based on minimum of 5 samples taken over a 30-day period.	MPN shall not exceed a median value of 14, with not more than 10% of the samples exceeding 43, nor exceed 800 on any day.	MPN or MF cannot exceed monthly average of 200, nor exceed 400 in 10% of samples, nor exceed 800 on any day. Monthly averages must be based on minimum of 5 samples taken over a 30-day period	MPN or MF counts shall not exceed monthly average of 200, nor exceed 400 in 10% of samples, nor exceed 800 on any day. Monthly averages must be based on minimum of 5 samples taken over a 30-day period
*Copper	µg/L	Cu ($_e$(0.8545[lnH]-1.465)	2.9	Cu ($_e$(0.8545[lnH]-1.465)	0.9
Nitrate	mg/L	10, or concentration that exceeds nutrient criteria.			
Nutrients		Discharge of nutrients is limited as needed to prevent violations of other standards. Man-induced nutrient enrichment (total nitrogen or total phosphorus) is considered degradation (Section 62-302.300, 62-302.700, and 62-4.242 FAC). Nutrient concentrations in a body of water cannot be altered so as to cause an imbalance in natural populations of aquatic flora and fauna.			
Phosphorus	µg/L		0.1		0.1

*Florida surface-water quality standards for metals were used as assessment endpoints. The standard for copper in Class I and Class III freshwater bodies takes into account water hardness ($CaCO_3$) and provides a range from 0.00361 mg/L to 0.036 mg/L (corresponding to a range in $CaCO_3$ from 25 to 400 mg/L).
MPN = most probable number
MF = membrane filter

In addition to the above classes of water bodies, Florida has a category for Outstanding Florida Waters and Outstanding National Resource Waters. This generally refers to waters of exceptional recreational or ecological significance that are found within national and state parks and wildlife preserves. A complete listing is available under 62-302 and includes the waters of the Everglades National Park. These waters fall under Florida's Antidegradation Policy and are afforded the highest protection.

In December 2000, the EPA published recommendations for ambient freshwater quality criteria for different regions around the country. These water-quality goals or recommendations are intended to assist states and tribes in establishing nutrient limits for water bodies that are consistent with Section 303(c) of the Clean Water Act. These criteria are recommended, not required.

Using historical data and reference sites, the EPA determined that the unimpacted lakes and reservoirs of South Florida (Ecoregion XIII) had a mean background predevelopment total nitrogen concentration of 1.27 mg/L (US EPA, 2000a). The 3 mg/L standard for treating nitrogen before discharge represents a concentration that is 2.4 times higher than this background.

Similar mean background predevelopment nitrogen concentrations for rivers and streams in South Florida are not currently available. In Ecoregion XII, which includes central and northern Florida (as well as portions of Alabama, Georgia, and Mississippi), the EPA recommends a background total nitrogen concentration of 0.9 mg/L in streams and rivers (US EPA, 2000b). The 3 mg/L standard for treatment before discharge represents a concentration that is approximately 3.3 times higher than this background level.

Total phosphorus includes all forms of phosphorus, both inorganic and organic. For streams and rivers in nearby Ecoregion XII, the EPA recommends a total background phosphorus water-quality criterion of 40.0 μg/L, or 0.040 mg/L (US EPA, 2000b). This is two orders of magnitude lower than the AWT treatment standard. Florida regulations require that plants that discharge to surface-water bodies treat wastewater so that the final concentration of total phosphorus in the discharged effluent is 1 mg/L. The EPA has determined that the unimpacted lakes and reservoirs of South Florida (Ecoregion XIII) had a mean background predevelopment total phosphorus concentration of 17.50 μg/L, or 0.0175 mg/L (US EPA, 2000a). The standard for AWT-treated wastewater, 1 mg/L, represents a concentration 57 times larger than this recommended background level for lakes and reservoirs.

7.5 Problem Formulation

Human health and ecological risks that may be associated with the discharge-to-surface-waters option are expected to be highly site-specific. There may be substantial differences of scale in important physical processes and variations in the assimilative capacity of individual water bodies. Therefore, this option-specific risk analysis focuses on whether surface-water quality standards are likely to be exceeded by actual discharges. This is coupled with a review of the types of adverse effects that might be anticipated where surface-water quality standards are exceeded. Implicit in this approach is an assumption that surface-water quality standards are adequately protective of human and ecological health. For one area where this assumption may be suspect (standards for nutrient discharges), a set of surface-water quality recommendations serve to expand this analysis to include additional considerations.

7.5.1 Potential Stressors

Potential stressors entrained or dissolved in treated wastewater are discharged to surface-water outfalls located in canals, creeks, or estuaries. Wastewater constituents that may act as stressors to human or ecological health include nutrients (nitrogen and phosphorus), certain metals, organic compounds, pathogenic microorganisms, and hormonally active agents. A group of potential "secondary stressors" (for example, shifts in community structure and productivity) may at the same time be caused by the presence of wastewater constituents and, in turn, be the cause for additional adverse effects. Secondary stressors include such things as changes to plant, invertebrate, and fish community structure; growth of invasive species; reduction in oxygen levels; and harmful algal bloom.

7.5.1.1 Nutrient Stressors

Because most, if not all, of the permitted discharges to surface waters eventually reach coastal embayments, the risk assessment of these discharges resembles the risk assessment of the ocean outfall option in many ways. Nutrient stressors are an example. Nutrients act as ecological stressors when present in surface waters at sufficient concentration to overstimulate primary production (leading to eutrophic conditions) or otherwise cause adverse changes in ecosystem health or structure (for example, loss of native species, growth of invasive species).

Nitrogen limitation in coastal and ocean waters was reviewed in Chapter 6 (see Paerl, 1997; Dugdale, 1967; Ryther and Dunstan, 1971; Codispoti, 1989; Eppley, et. al., 1979). Freshwater ecosystems are typically characterized by phosphorus limitation (Schindler, 1977, 1978; Smith, 1982). Phosphorus limitation is generally stems from low levels of naturally occurring dissolved inorganic phosphorus. However, ecosystem responses to additions of phosphorus will depend on both the levels of additional phosphorus made available and the levels of nitrogen that are latent in the ecosystem, often as a result of human activity (such as agricultural inputs). In Florida, natural ambient levels of phosphorus may be higher than in other areas of the country because of high phosphorus content in the regional geology (Valette-Silver et. al., 1999).

The National Research Council concluded that, while nitrogen is important in controlling primary production in coastal waters and phosphorus is important in freshwater systems, both need to be managed to avoid overproduction (National Research Council, 2000). The causes of eutrophication in fresh and marine ecosystems are not identical but do reflect ecological and biogeochemical processes. In either case, the relative inputs of nitrogen and phosphorus and the extent to which nitrogen fixation can alleviate limitation play a crucial role in determining the limiting nutrient to production in aquatic ecosystems. The limiting nutrient is the nutrient in shortest supply in a natural system. In marine waters, nitrogen is generally present in low concentrations, while in fresh water, phosphorus is present in low concentrations.

While phosphorus limitation in fresh water seems universal, there are exceptions to the general principle that nitrogen is limiting in coastal ecosystems. For example, the Apalachicola estuarine system on the Gulf coast of Florida appears to be phosphorus-limited (Myers and Iverson, 1981). Howarth (1988) and Billen et al. (1991) suggest that this is related to the relatively high ratio of nitrogen to phosphorus inputs. Howarth et al. (1995) suggests that there is a tendency for estuaries to become more nitrogen-limited as they become more affected by humans and as nutrient inputs increase overall.

In nearshore tropical marine systems, phosphorus tends to be more limiting for primary production (Howarth et al., 1995). In some major estuaries, nutrient limitation switches seasonally between nitrogen and phosphorus. Examples of such seasonally varying nutrient limitation include the Chesapeake Bay (Malone et al., 1996) and portions of the Gulf of Mexico, including the so-called "dead zone" (Rabalais et al., 1999). Tampa Bay has become a nitrogen-limited system instead of a phosphorus-limited system because of the long-term mining of phosphorus. In contrast, Florida Bay is phosphorus-limited (Bianchi et al., 1999).

7.5.1.2 Metals

Trace metals in wastewater are potential stressors because they may cause adverse human health and ecological effects at high concentrations. Trace metals are frequently elevated in wastewater as a result of common industrial usage. Levels in treated wastewater are, in general, greatly reduced, but trace metals are still frequently used as tracers of wastewater in the aquatic environment (Matthai and Birch, 2000; Flegal et al., 1995; Hershelman et al., 1981; Ravizza and Bothner, 1996; Morel et al., 1975). Additional sources of metals that may contribute to levels present in surface-water bodies include combustion of fossil fuels, mining activities, stormwater runoff, atmospheric deposition, and other surface-water and groundwater sources (Burnett et al., 1980; Finney and Huh, 1989; Forstner and Wittman, 1979; Huh et al., 1992; Huntzicker et al., 1975; Klein and Goldberg, 1970).

Metals can bioaccumulate in the food chain, thus having adverse secondary impacts on an ecosystem. For example, arsenic may bioaccumulate in aquatic organisms. However, there is considerable variability in aquatic food-web bioaccumulation (Penrose et al., 1977; Woolson, 1977). See Chapter 3, Methodology, for further description of metals as a potential stressor in the environment.

7.5.1.3 Organic Compounds

Potential organic stressors that may be present in treated wastewater include volatile organic compounds (VOCs), synthetic organic compounds (such as pesticides, herbicides, surfactants), trihalomethanes, and some hormonally active agents (endocrine disruptors). See Chapter 3, Methodology, for a further description of organic compounds as potential stressors in the environment.

Hormonally active agents may have potentially adverse effects on aquatic organisms, based on the scientific literature. A study conducted in the United Kingdom found that wastewater induced vitellogenin synthesis in caged and wild fish several kilometers downstream of points of discharge (Rodgers-Gray et al., 2000); vitellogenin is a protein important to yolk production. These effects were induced at dilutions of treated wastewater ranging from 9.4% to 37.9%. Similar studies were conducted in the United States. However, there was no apparent vitellogenin induction in fathead minnow (*Pimephales promelas*) in response to exposure to treated wastewater (Nichols et al., 1998).

Studies in Florida have documented potential adverse effects from exposure to hormonally active agents in upland and freshwater organisms, including the Florida panther (Facemire, et al., 1995) and American alligator (Guillette, 1994, Semenza, 1997). However, these studies do not document the sources of these agents.

These studies indicate that hormonally active agents may be capable of causing potentially adverse health effects in aquatic organisms. However, more information is needed to determine how these compounds cause adverse reactions.

7.5.1.4 Pathogenic Microorganisms

Pathogenic stressors that may be present in treated wastewater include enteric bacteria, protozoans, and viruses associated with human or animal wastes. Secondary treatment, chlorination, and filtration generally remove all viruses, helminthes, and pathogenic bacteria. However, the protozoans *Giardia* and *Cryptosporidium* form cysts that are resistant to chlorination and that can only be removed through careful filtration. The Florida DEP has evaluated monitoring data from reclaimed-water treatment facilities that treat wastewater intended for reuse or discharge to surface waters. Wastewater treated at some facilities still contains levels of *Cryptosporidium* and *Giardia* that may pose human health risks, despite chlorination and filtration (York et al., 2002).

Much of the information concerning survival and transport of pathogenic protozoans discussed in Chapter 4 applies to discharges to surface waters. *Cryptosporidium* oocysts, for example, have a T_{90} (that is, the time needed to inactivate 90% of the population) of approximately 200 days (Robertson et al., 1992). This time frame is long enough that discharged effluent traveling over short distances and short travel times may still contain some pathogenic protozoans.

Contamination of Florida's coastal environments with enteric viruses, bacteria, or protozoans is a widespread and chronic problem. This is notably the case for Tampa Bay, Sarasota Bay, and the marine environment surrounding the Florida Keys. There are a number of potential causes for this. They include the prevalence and high density of onsite sewage-disposal systems (such as septic systems), the presence of predominantly porous and sandy soils, and karst topography and the hydrologic connection between groundwater and coastal embayments and estuaries (Lipp et al., 2001; Paul et al., 1995).

7.5.1.5 Secondary Stressors

Secondary stressors are the result of exposure to the potential stressors discussed above and include the following:

- Increased primary productivity
- Increased oxygen demand and hypoxia
- Shifts in community structure caused by anoxia and hypoxia
- Changes in phytoplankton community structure
- Harmful algal blooms

- Marine mammals and human impacts from harmful algal blooms
- Degradation of sea-grass and algal beds and formation of nuisance algal mats
- Coral reef destruction
- Trophic impacts.

Sea-grass degradation in Tampa Bay, Sarasota Bay, and Indian River Lagoon has been attributed to nutrient loading, from both point and nonpoint sources. Sea grass serves as a valuable habit for juvenile fish, some marine mammals, and shellfish as it provides food, oxygen, and refuge. In addition, sea grass stabilizes the bottom substrate, keeping sediment out of the water column. The loss of sea grass can also cause secondary effects by adversely affecting other species that utilize this habitat. Nutrient loading that increases phytoplankton populations can damage sea grass; this in turn decreases light transmission to the substrate.

The increase in production can also result in increased organic loading that, upon decomposition, utilizes oxygen, thus creating hypoxic or anoxic conditions. These conditions can result in fish kills or a decrease in available fish habitat.

Changes in nutrient concentrations in the water column can alter the phytoplankton community structure. This may result in increased nuisance or harmful algal blooms. In addition, the availability of silica and iron appears to play a role in coastal eutrophication and may promote the formation of harmful algal blooms (National Research Council, 2000).

Harmful algal blooms (HABs) pose particular concerns in brackish, coastal, and estuarine environments. Harmful algal blooms taxa and associated problems in coastal or estuarine environments are described in the Chapter 6. The causes of harmful algal blooms are still controversial. They include a variety of physical, chemical and biological changes, such as climate change, increased pollution and nutrient inputs, habitat degradation through dredging, resource harvesting and regulation of water flows, failure of grazers to control algal growth, and better monitoring. It is uncertain whether higher numbers of harmful algal bloom reports in recent years are a result of an actual increase in harmful algal blooms or better water-quality monitoring.

Harmful cyanobacterial ("blue-green") algal blooms can occur in warm stratified areas in embayments and estuaries, where nitrogen concentrations are low, salinities are reduced, and phosphorus is enriched through upwelling, eddies, or mixing. Phosphorus limitation is generally more important than nitrogen limitation (Sellner, 1997). In Florida, extensive blooms of the cyanobacterium *Lyngbya majuscula* were documented in Tampa Bay in 1999 and from Sarasota Bay to Tampa Bay in 2000. Although this species is not toxic, it is a nuisance alga because it produces large, slimy, brown odorous floating mats (Florida Fish and Wildlife Conservation Commission, 1999). The causes for this bloom are unknown; it is not believed that discharges of treated effluent played a significant role.

Harmful algal blooms of *Gymnodinium breve* occur frequently off the southwest coast of Florida, especially from Clearwater to Sanibel Island, occurring in 21 of the last 22 years

(Boesch, et al., 1997). Blooms move inshore and can have impacts on the health of humans or wildlife. In 1996, more than 150 manatees died from exposure to brevetoxin during prolonged red tides along the southwest coast of Florida (Steidinger et al., 1996). There is some evidence that dense blooms of *Gymnodinium* rely on new nutrient inputs; human impacts to watersheds may be responsible for extending the duration and adverse effects of red tides once they enter nearshore areas (Boesch et al., 1997).

Effects of secondary stressors also include changes in trophic processing of organic matter, uptake and bioaccumulation, biodiversity and populations, and growth of invasive species displacing native species.

7.5.2 Potential Receptors and Assessment Endpoints

Assessment endpoints represent discrete natural resource values or functions deemed important to local ecology or natural communities. Water-quality standards are set based upon such endpoints. For example, maintenance and protection of aquatic life might be one such endpoint. Other endpoints might be fishable and swimmable waters. Water-quality criteria then would be set, based on reaching that goal. As discussed in section 7.4.2, Florida uses a class system to designate uses of water bodies and applies water-quality standards to meet those uses.

The water-quality standards are set based upon the best science available and are conservative. Still, there are many unknowns and uncertainties, particularly when setting standards related to protecting complex ecosystems. For example, many times numerical standards are not set for nutrients in water bodies because the ecoystem effects are very site-specific.

Canals, which are a frequent receptor for discharge of treated wastewater into surface-water bodies, are often hydrologicly connected to groundwater and are recharged by groundwater. Adams (1991) examined water in the surficial aquifer and canals in Martin and Northern Palm Beach counties and concluded that groundwater quality did not seem to be affected by canal water, probably because the aquifer is discharging to the canal rather than the canal recharging the aquifer. However, water from canals may enter the surficial aquifer when canals are used as an irrigation source. Drinking-water receptors (underground sources of drinking water (USDWs) or water-supply wells) may be exposed where surface waters have a direct hydrologic connection to the groundwater resource

7.5.3 Potential Exposure Pathways

When human health or ecological receptors are exposed to wastewater constituents in sufficient concentration, these receptors may be at risk for potentially adverse health effects. Complex processes and interactions govern how wastewater discharged to surface waters will move and behave. These processes and interactions define the pathways that may expose receptors to stressors present in treated wastewater.

Potential transport processes include advective transport in stream and nearshore currents, and estuarine and tidally driven circulation. The action of these transport processes varies substantially over time and space. Patterns and mechanisms of transport are often quite different in water bodies of different sizes, shapes, and orientations. Transport processes can also vary substantially within water bodies, over the course of time, and in response to localized changes in depth, currents, temperature, and many other factors.

The capacity of water bodies to dilute or assimilate wastewater constituents is fundamentally important to the fate of potential stressors in surface-water ecosystems and to the risks that may be posed by such stressors. In this respect, the rate of flow through a canal or creek and the rate of flushing for an embayment or lagoon are key parameters that influence both fate and risk. In general, adverse effects are expected to be greater in smaller surface-water bodies that flush slowly than in larger water bodies that are well flushed.

Sedimentation and flocculation are important physical and chemical processes that can act to take wastewater constituents out of the water column. Turbulent mixing and resuspension frequently act to counteract these processes, setting up a dynamic equilibrium in which materials are exchanged (over time and space) between the water column and sediment layer. Where conditions are conducive to sedimentation or flocculation, the sediment layer can become a sink, potentially affecting local flora and fauna at the sediment interface.

Potential exposure pathways for ecological receptors include direct ingestion of water or sediments, dermal contact and other forms of uptake (for example, diffusion into submerged plants and soft-bodied invertebrates), and bioaccumulation or food-chain bioconcentration. Ecological receptors are exposed to secondary stressors, such as the disappearance of favorite prey items or reduced levels of available oxygen, through their trophic relationships and position within the larger biological community.

Potential human exposure pathways include direct ingestion or dermal contact with surface water and ingestion of contaminated fish, shellfish, or other plants and animals exposed to treated wastewater. Drinking-water receptors may be exposed where surface waters have a direct hydrologic connection to the groundwater resource.

7.5.4 Conceptual Model of Potential Risk for the Discharge-to-Surface Waters Option

Figure 7-1 presents a generic conceptual model for the discharge-to-surface-waters wastewater management option. The primary source of potential stressors is defined as the wastewater treatment plant from which treated effluent is routed to one or more surface-water outfalls. The rate of discharge may vary, depending on the size and operational status of the facility. but is generally measured in millions of gallons per day.

Treated wastewater is discharged directly to surface-water bodies. These are predominantly small, flowing, fresh-to-brackish bodies of water (canals, creeks, and estuaries). According to the Florida DEP, discharge to closed bodies (ponds and lakes) is no longer practiced in South Florida. Wastewater is typically treated to a higher level than effluent discharged through ocean outfalls. Treatment includes secondary treatment and basic disinfection, followed by filtration and, in some cases, nutrient reduction and dechlorination to remove harmful chlorination by-products. In the model, nutrient limitation varies, depending on whether disposal into freshwater, estuarine, or coastal marine waters is conducted.

Potential ecological receptors include the wildlife, waterfowl, fish, and invertebrates that are dependent on canals, estuaries, and other surface-water ecosystems for food and habitat.

Potential human receptors include recreational fishermen, swimmers, agricultural workers, and others whose work or recreation brings them into close proximity or contact with surface-water bodies that receive effluent discharges. Waters classified as fishable and swimmable are assessment endpoints meant to protect these ecological receptors.

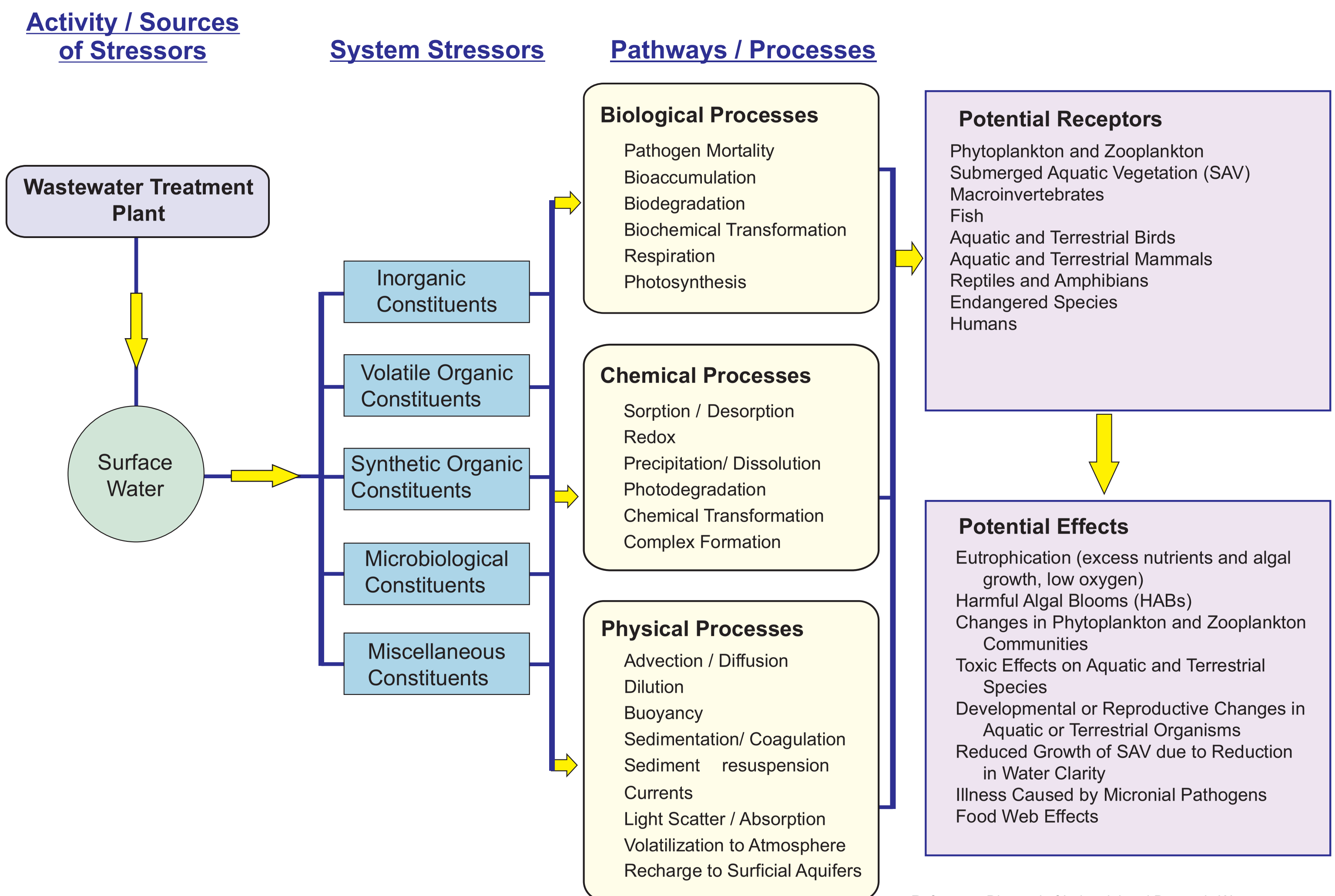
Drinking-water receptors may be exposed to wastewater when surface waters have direct hydrologic connection to the groundwater resource. While this study did not find any evidence of wastewater discharging to surface waters in direct connection to groundwater wells in South Florida, it is a consideration when analyzing potential receptors.

7.6 Risk Analysis of the Discharge-to-Surface-Waters Option

In this section, data are integrated into the conceptual model for the discharge-to-surface-waters option. Actual data on stressors, receptors, and exposure pathways are used to examine potential risks.

Discharge monitoring data from several public treatment facilities, as well as a database provided by the Florida DEP (2002b), were used to examine where (and to what extent) the discharge-to-surface-waters option is used in South Florida. Staff from Florida DEP assisted in determining which options are utilized by specific treatment facilities (personal communication, Kathryn Muldoon, February, 2002).

Information to describe the volume and quality of treated wastewater discharged to surface waters was limited. In order to characterize potential stressors and stressor concentrations, data were obtained from three AWT plants that discharge to surface waters (the City of Cape Canaveral and South Beaches treatment facilities in Brevard County and the Howard F. Curren treatment plant in Hillsborough County). In addition, information on AWT effluent managed at two wastewater treatment plants in Sarasota County (Gulfgate and Southgate Wastewater Treatment Plants) was obtained from the report by Englehardt et al. (2001) (Appendix Table 1-1). No data were available to characterize discharges to surface waters treated to less-than-AWT standards.



Reference: Disposal of Industrial and Domestic Wastes: Land and Sea Alternatives, National Academy of Sciences, 1984.

Figure 7-1. Conceptual Model of Potential Risks for the Surface Water Option

To describe the proximity and vulnerability of receptors, information was obtained regarding biological communities present in the receiving water bodies, particularly sensitive or vulnerable populations. A review of the scientific literature provided information about potential exposure pathways, adverse impacts, and risks. Wherever available, previous studies and investigations were used to appropriately expand the scope of this analysis.

7.6.1 Evaluation of Stressors and Assessment Endpoints

7.6.1.1 Nutrients

Annual average concentrations of total nitrogen in treated wastewater for 1999 and 2001 were calculated from monthly monitoring report averages for the City of Cape Canaveral's AWT wastewater treatment plant (Appendix Table 1-1). The annual average concentration of total nitrogen during this period ranged from 0.752 to 0.970 mg/L; the maximum monthly average was 1.353 mg/L, and the minimum monthly average was 0.321 mg/L of total nitrogen. These values are well below the 3 mg/L AWT standard for treatment. Background concentrations of nitrate (a component of total nitrogen) at two ocean locations off the east coast of Florida reported in Hazen and Sawyer (1994) were 0.11 mg/L and 0.16 mg/L. One monitoring result for nitrate for the City of Cape Canaveral's wastewater treatment plant revealed a nitrate concentration in treated effluent of 0.062 mg/L. This is an order of magnitude lower than background concentrations of nitrate reported for the SEFLOE studies in an open ocean environment (summarized in Hazen and Sawyer, 1994).

Annual average concentrations of total phosphorus for 1999 and 2001 were calculated from monthly monitoring report averages for the City of Cape Canaveral's AWT wastewater treatment plant (Appendix Table 1-1). The annual average concentration of total phosphorus during this period ranged from 0.119 to 0.152 mg/L; the maximum monthly average was 0.273 mg/L, and the minimum monthly average was 0.064 mg/L total phosphorus. The annual average concentrations of total phosphorus are higher than recommended background levels for total phosphorus in fresh water. Thus, the excess phosphorus may pose some ecological risks.

Permitted concentrations of nitrogen and phosphorus (3 and 1 mg/L, respectively) in AWT-treated effluent discharged to surface waters are often greater than background concentrations in unimpacted water bodies. Phosphorus concentrations in AWT effluent were generally significantly higher than recommended background concentrations for fresh waters. However, as indicated above, actual nitrate concentrations in AWT effluent can be lower than background oceanic nitrate concentrations.

Long-term water-quality and biological monitoring in Hillsborough Bay indicates that water quality and clarity have improved and shoal grass (*Halodule wrightii*) has recovered since AWT was implemented at the Howard F. Curren Wastewater Treatment Plant (City of Tampa Bay Study Group, 2001b).

Given the limited use of this disposal option and limited data on actual discharged effluent, it is difficult to estimate risk for this option except in these more general terms relating to water-quality standards. Nevertheless, nutrient loading is one of the top reasons for impairment of surface-water bodies in Florida. It is likely that point sources are part of this larger problem. Rivers, streams, and canals typically empty into other water bodies that can be impacted by nutrient enrichment. In some instances, treatment plants discharge to a wetland before ultimately discharging to surface waters; when this occurs, the nutrient load decreases and thus the risk from this type of disposal may be diminished.

7.6.1.2 Metals

Concentrations of all inorganic and secondary analysis metals in AWT effluent reviewed for this study were below standards for drinking water quality (Appendix Table 1-1). Copper concentrations in AWT effluent were similar to concentrations found in secondary-treated effluent (Englehardt et al., 2001). Total copper in advanced treated wastewater was 0.003 mg/L. This is below copper water-quality standards in Florida. Because the concentrations of copper in wastewater effluent reported by utilities in this study were below water-quality standards, it is unlikely that this constituent poses significant risks to human or ecological health. For the Cape Canaveral plant, copper concentrations were below detection limits (<0.0005 mg/L).

7.6.1.3 Organic Compounds

Concentrations of trihalomethanes, synthetic organics, and volatile organics were below drinking-water standards (Appendix Table 1-1). Compared to the Florida standards for surface water quality, all trihalomethanes in AWT wastewater were below Class II and Class III standards for fresh and marine surface-water quality. Class I standards, which apply to surface waters used as drinking-water supplies, were not met by the AWT effluent monitoring results reviewed for this study. However, none of the AWT plants surveyed in this report discharge treated effluent to Class I surface-water drinking supplies.

All synthetic and VOCs that were analyzed from one monitoring sample of treated effluent by the City of Cape Canaveral wastewater treatment facility were below detection limits (Appendix Table 1-1).

The representative contaminant chosen to evaluate potential risk include a number of estrogenic and estrogen-like substances. Estrogen equivalence is a measure of the response of breast cancer cells to exposure to strongly estrogenic substances, such as hormone replacement and birth-control pills (Frederic Bloettscher, personal communication). Estrogen equivalence was measured from two grab samples at the Gulfgate and Southgate treatment plants in Sarasota, Florida. Both of these plants treat to AWT levels and discharge to surface-water creeks. The average concentration of estrogen-equivalence substances in the treated wastewater effluent was 3.253 nanograms per liter (ng/L) (Frederic Bloettscher, personal communication).

At this point, this information only indicates that these substances may be present in treated wastewater intended for disposal into surface water. Recent literature suggests that concentrations below 1 ng/L can cause vitellogenin levels to increase in aquatic organisms (Sadik and Witt, 1999; Larsson, et al., 1999). The literature suggests that more study is needed concerning the concentrations at which endocrine disruption may occur from biodegradation byproducts.

No information is available concerning concentrations of estrogen-like compounds in ambient surface waters near the outfall sites, nor in ecological receptors at or near the outfall sites. Ongoing and future research should provide a better framework for discussing these compounds and evaluating their risks.

7.6.1.4 Pathogenic Microorganisms

Monitoring data reported by the city of Cape Canaveral to the Florida DEP for its National Pollutant Discharge Elimination System permit indicate that, between 1999 and 2001, the maximum concentration of fecal coliforms in treated effluent (measured monthly) ranged from 0 to 8 colonies per 100 mL (Cape Canaveral NPDES Database, 1999–2001). As noted above, a certain number of fecal coliforms are permitted, up to a limit of 200 fecal coliforms per 100 mL of effluent, for all but Class I surface waters. These concentrations do not meet drinking-water standards.

The Howard F. Curren Wastewater Treatment Plant in Tampa Bay reported annual sampling results in 2000 and 2001 for *Giardia lamblia* and *Cryptosporidium*, pathogenic protozoans that can cause gastrointestinal illness in humans when ingested (David York, pers. comm.). In 2000, the concentration of *Giardia lamblia* and *Cryptosporidium* were each less than 0.7 cysts per 100 L of effluent. In 2001, the concentration of *Giardia lamblia* was less than 0.29 cysts per 100 L of effluent, and the concentration of *Cryptosporidium* was 2.33 oocysts per 100 L of effluent. These numbers are below the DEP's recommended limit of 5.8 per 100 L for both *Cryptosporidium* and *Giardia*. Monitoring of other wastewater treatment facilities in Florida indicates that a few facilities do not meet the informal standard of 5.8 per 100 L, despite the fact that the effluent is filtered (York et al., 2002).

7.6.2 Evaluation of Receptors and Exposure Pathways

Some potential ecological receptors in water bodies in Florida that receive treated wastewater are described below. Water-quality problems that have arisen or been corrected through the implementation of improved wastewater treatment are noted.

- **Submerged aquatic vegetation** (such as sea grasses) populations are abundant in the nearshore areas surrounding South Florida. In recent years, there have been documented changes in the abundance of sea grass in the nearshore environment. For example, in Tampa Bay, there have been recent declines in sea-grass populations, but this has occurred after several years of sea-grass expansion throughout the bay. In the late 1980s and early 1990s, sea grasses were returning at the rate of 500 acres a year as Tampa Bay responded to improvements in water quality resulting from improvements in wastewater treatment. The sea-grass expansion rate slowed to about 350 acres in the mid-1990s. The latest figures show an overall cumulative loss of sea grass to pre-1990 levels (Coastlines, Issue 11.4).

- **Bordering habitats** (such as mangroves and salt marshes) are located throughout the nearshore estuarine environment in South Florida. Like sea-grass habitats, these areas offer food and refuge to many aquatic species and are affected by increased nutrients.

- The Indian River Lagoon supports one of the most diverse **bird populations** in the United States, with 125 breeding species and 172 species that over-winter in the area (Adams et al., 1996). Many bird species in the region are impacted by human activities, especially activities that contribute to habitat loss and fragmentation. In 1987, the dusky seaside sparrow became extinct in the Indian River Lagoon because of alterations to coastal marsh habitat (marsh impoundment)**.** Avian communities are also susceptible to overexploitation (primarily hunting) and to the adverse effects of widespread use of chemicals (especially DDT).
- **Marine mammals,** such as the West Indian manatee and the Atlantic bottlenose dolphin, inhabit lagoons and estuaries along the Florida coast. One-third of the endangered Floridian population of West Indian manatee (*Trichechus manatus*) resides in the Indian River lagoon. Collisions with boats pose the most significant threat to these populations, at least from human activities. However, *Cryptosporidium* and *Microsporidium* infections have been implicated in recent manatee deaths along the Gulf Coast of Florida, according to biologists at Tampa's Lowry Park Zoo (Grossfield, 2002). Dolphin (*Tursiops truncatus*) populations are believed to be stable. Approximately 20 dolphin fatalities are reported annually; 8% to 12% of these fatalities are believed to be related to boat accidents or fishnet entanglement. A fungal skin disease that affects approximately 12% of the dolphin population may be linked to water quality, as documented by the Treasure Coastal Dolphin Project conducted in 1994 (Adams et al., 1996).

- Both **green and loggerhead turtles** are on the U.S. Fish and Wildlife Service list of threatened and endangered species (Adams et al., 1996; Gilmore, 1995; Gilmore et al., 1981). The green turtle (*Chelonia mydas mydas*), a state and federally endangered species, inhabits the Indian River Lagoon. Boat collisions and fishing line entanglement are believed to be the principal causes of sea turtle mortality. However, 40% to 60% of green turtles surveyed in the Indian River Lagoon were found to be infected with fibropapillomatosis; this disease may be linked to water quality (Ehrhart and Redfoot, 1995).

- As of January 1994, 782 **fish species** were documented in the east-central Florida region. At least half of these species use estuaries and lagoons, such as the Indian

River Lagoon, at some point in their life histories (Gilmore, 1995; Gilmore et al., 1981).

Toxicity testing results from the city of Cape Canaveral AWT Wastewater Treatment Plant in June 2001 (City of Cape Canaveral, 2001) revealed that the survival rate of *Ceriodaphnia dubia* ranged from 85% to 95% for undiluted treated wastewater. The survival rate for *C. leedsi* was 100% for all tests. While the data were limited, this indicates that the AWT-treated wastewater is not acutely toxic.

There is no direct evidence (such as the use of tracer studies) that indicates that constituents in AWT-treated wastewater are taken up by aquatic biota or human receptors in the coastal embayments or canals reviewed. However, although there is no direct evidence, indirect evidence indicates that discharges of treated wastewater do affect water quality on a regional scale. Zhou and Rose (1995) and City of Tampa Bay Study Group (2000b) reported that water quality in Sarasota Bay and Hillsborough Bay (Tampa Bay) improved after wastewater treatment plants that discharged to rivers or the bay itself upgraded their wastewater treatment to meet tertiary or advanced standards. This suggests that the high nutrient levels previously measured in the bay were at least partly the result of discharges of secondary-treated effluent.

Some potential ecological receptors, such as endangered species, may be more susceptible to harm and may be at risk from concentrations less than the applicable standards. Additionally, eutrophication is site-specific as it is greatly influenced by physical and biological processes. Addition of nutrients and, indeed, any constituents that may be present in treated effluent needs to be examined in a site-specific context to truly evaluate risk.

Little information was found on ecological receptors in canals that may be receiving wastewater effluent. However, estuaries examined in this study that are receiving treated wastewater contain marine mammals, fish, and birds that are known to be at risk from other effects of human development.

In terms of the applicable water-quality standards, surface waters receiving discharges of treated wastewater reviewed in this report were designated as Class III waters. Class III water-quality standards are meant to protect a healthy population of fish and wildlife and provide recreational uses. Compared to these standards, the quality of AWT effluent was often well below the required minimum concentrations.

Physical mixing and dilution are important large-scale processes that will act to decrease concentrations of stressors in a water body. This is especially true for streams, rivers, estuaries, and coastal embayments that are well mixed. Such dispersion and dilution will decrease the risks to human and ecological receptors.

There is a strong coupling of groundwater and surface water in South Florida. At present, there are few estimates of the hydrologic fluxes between groundwater and surface water in south Florida. However, in recent studies in the Everglades, it was found that extensive human manipulation of the natural drainage system in southern Florida has altered hydrology that has led to increased recharge and discharge in the north-central Everglades (USGS, 2002). Additional evidence of interaction between groundwater and surface waters in the Everglades was provided when mercury was found to be recharged from surface water to groundwater and stored in the surficial aquifer. Indeed two-way exchange of surface water and groundwater may be a localized phenomenon, as was found in Taylor Slough (USGS, 2002).

Canals, which are a frequent receptor for discharge of treated wastewater into surface-water bodies, are often hydrologicly connected to groundwater and are recharged by groundwater. Adams (1991) examined water in the surficial aquifer and canals in Martin and Palm Beach counties and concluded that groundwater quality did not seem to be affected by canal water. This suggested that the aquifer is discharging to the canal rather than the canal recharging the aquifer. However, water from canals may enter the surficial aquifer when canals are used as an irrigation source. Drinking-water receptors may be exposed where surface waters have a direct hydrologic connection to the groundwater resource.

7.7 Final Conceptual Model of the Discharge-to-Surface-Waters Option

This disposal option presents limited risks, because the volumes of treated effluent discharged to surface water are much smaller than volumes discharged via ocean outfalls or Class I injection wells and because the discharges are typically discharged intermittently.

- The degree and kind of treatment of wastewater is an important factor determining effluent quality and therefore risk. To discharge to surface waters in the state of Florida, wastewater treatment plants are likely to treat using AWT. AWT treats wastewater to a higher standard than secondary treatment, removing additional nutrients, organic compounds, and total suspended solids from the effluent.
- Several of the AWT standards (for example, nutrients) are elevated when compared to natural background levels of these compounds in unimpacted surface waters and when compared to the EPA's recommended standards for unimpacted surface waters, which are based on monitoring of more pristine water bodies. Nutrients, both nitrogen and phosphorus, pose ecological risks for the aquatic environment as they may increase primary production, alter phytoplankton communities, and encourage or exacerbate the growth of harmful algal blooms. The data available reveal that wastewater treatment facilities often have the ability to remove nitrogen to well below the standard required, which would reduce risk. While phosphorus met treatment standards, the concentrations that remain in treated wastewater are often higher than recommended water-quality standards, based on unimpaired waters.
- There is a lack of water-quality monitoring data and tracer studies that would show whether effluent constituents are taken up by receptors.

- There are no effluent or surface-water quality standards for *Cryptosporidium* and *Giardia*, although the Florida DEP has recommended that numerical standards corresponding to a 1 in 10^{-4} human illness risk be adopted for *Cryptosporidium* and *Giardia* in reclaimed water (York et al., 2002). These recommendations are 5.8 oocysts per 100 L and 1.4 cysts per 100 L for *Cryptosporidium* and *Giardia*, respectively. For comparison, background concentrations of *Cryptosporidium* oocysts in North American water bodies, such as lakes, rivers, springs, and groundwater, averaged 44, 43, 4, and 0.3 oocysts per 100 L, respectively (York et al., 2002).
- Concentrations of pathogenic microorganisms in treated wastewater from the Howard F. Curren facility were well below the standards for discharges to surface waters for Class III waters. Concentrations of the pathogenic protozoans *Giardia* and *Cryptosporidium* in effluent from the Howard F. Curren AWT plant were very low.
- Monitoring of pathogenic protozoans at other wastewater treatment facilities in Florida indicates that a few facilities do not meet the recommended limit of 5.8 per 100 L, despite the fact that filtration is done (York et al., 2002). While human health risks from pathogenic protozoans are generally very low, they are not zero.
- Facilities that nitrify appear to be better at removing *Giardia* than facilities that do not nitrify (York et al., 2002).
- All inorganic compounds, including nutrients and metals, measured in AWT effluent were below drinking-water-quality standards. Copper was used as a surrogate because of its known toxicity in the aquatic environment. Copper concentrations in treated wastewater met Florida water-quality standards.
- Measured organic compounds, which include trihalomethanes, synthetic organics, and volatile organics, were below drinking-water standards. All synthetic and VOCs were below detection limits for the data reviewed in this study. Two grab samples for estrogen equivalence (hormonally active agents) revealed that these constituents are present in the effluent in relatively small concentrations (on the order of ng/L). Despite the lack of information on *in situ* concentrations, hormonally active agents pose ecological risks for aquatic ecosystems because of information from studies of their effects on other aquatic organisms elsewhere and because the effects are observed at very low concentrations.
- Toxicity testing of AWT effluent revealed no toxicity to aquatic organisms. The limited data available suggests that AWT effluent poses little or no ecological or human health risks.
- The relative risk of AWT-treated wastewater is lower than the risks posed by lesser-treated wastewater, based on improvement of water quality in Tampa Bay after AWT was required.
- Despite the relative lack of monitoring information from surface-water disposal outfalls and lack of evidence of adverse effects, it is reasonable to assume that, given the already-impacted nature of many surface-water bodies in South Florida, further discharge of nutrients in treated wastewater poses some ecological risks. The potential effects of nutrients on surface-water bodies will vary, depending on site-specific characteristics and the existing nitrogen loading from other sources. Preferably, a water-quality-based effluent limit (such as total maximum daily

loading) would be established that takes into account these site-specific characteristics and the carrying capacity of an individual surface-water body.
- In some areas, depending on existing impairment of water quality, it may be worthwhile to consider whether discharge of treated wastewater could help restore hydrology or water quality.

7.8 Gaps in Knowledge

Possible gaps in knowledge and their possible effects on this risk analysis are summarized below.

- The benefits or detriments of discharging AWT-treated wastewater into natural systems have yet to be proven.
- One of the most important gaps in knowledge concerns the numbers and significance of unpermitted, inadvertent, or occasional unplanned discharges of untreated or secondary-treated wastewater to surface-water bodies. Such discharges may occur at treatment facilities when storms or other causes combine to produce wastewater volumes that cannot be treated rapidly enough to keep up with incoming volumes. Rapid infiltration basins receiving untreated or secondary treated wastewater that overflow to nearby surface-water bodies, such as canals or creeks, provide examples of such untreated or minimally treated discharges. Such discharges are believed to occur at a number of South Florida facilities, including those at Miami-Dade South Treatment Facility. Although such discharges are outside the scope of this study because they are not a permitted form of wastewater management, they nonetheless pose high risks.
- The potential and actual human health and ecological health effects of exposure to AWT-treated effluent that has not been filtered to remove pathogenic protozoans to the levels recommended by the Florida DEP have yet to be determined. The ecological effects of pathogenic protozoans are only beginning to be documented; the latest example involves the implication of *Crytosporidium* and *Microsporidium* in mortality of manatees along the Gulf coast of Florida.
- Distinguishing between other sources of wastewater stressors and those derived directly from AWT-treated wastewater will be difficult unless specific tracers are utilized in studies designed specifically to distinguish different sources. Many other sources of stressors already have adversely affected Florida's surface waters and coastal waters.
- The effects of discharging wastewater treated to AWT standards into water bodies that are already adversely affected have not been explored or documented, according to available information. Comparing AWT-treated wastewater with water-quality recommendations based on pristine or unaffected ambient Florida waters also raises water-management questions that can only be answered through a combination of public process and scientific studies of the fate of these stressors and the capacity of the watershed or embayment to assimilate stressors without experiencing adverse effects.

REFERENCES

Adams KM. 1991. *Chemical Characteristics of Water in the Surficial Aquifer System and Major Canals, Martin and Northern Palm Beach Counties, Florida*. Boca Raton: Environmental Geochemistry Florida Atlantic University.

Adams AW, Ainsley JD, Busby DS, Day RA, Recore KA, Rice TB. 1996. *The Indian River Lagoon Comprehensive Conservation And Management Plan*.

Bianchi TS, Pennock JR, and Twilley RR. 1999. *Biogeochemistry of Gulf of Mexico Estuaries*. Ontario: John Wiley & Sons, Inc.

Billen G, Lancelot C, and Meybeck M. 1991. Nitrogen, phosphorus, and silicon retention along the aquatic continuum from land to ocean. In: *Ocean Margin Process in Global Change*. Mantoura RFC, Martin JM, and Wollast R, eds. New York: Wiley.

Boesch DF, Anderson DM, Horner RA, Shumway SE, Tester PA, and Whitledge TE. 1996. *Harmful Algal Blooms in Coastal Waters: Options for Preservation, Control and Mitigation*. NOAA Coastal Ocean Program Division Analysis Series No. 10. Silver Spring (MD): NOAA Coastal Ocean Office.

Boyer JN, Fourqurean JW, and Jones RD. 1997. Spatial characterization of water quality in Florida Bay and Whitewater Bay by multivariate analysis: Zones of similar influences (ZSI). *Estuaries*. 20: 743-758.

Brewster-Wingard GL, and Ishman SE. 1999. Historical trends in salinity and substrate in central Florida Bay: a paleoecological reconstruction using modern analogue data. *Estuaries*. 22(2B):369-383.

Brewster-Wingard GL, Ishman SE, Willard DA, Halley RB, Holmes CW. 1996. *The Biotic Record of Change in Florida Bay and the South Florida Ecosystem*. Internet: http://sofia.usgs.gov/projects/eh_fbswc/ehfbswcabfb96.html.

Burnett WC and Schaeffer OA. 1980. Effect of ocean dumping on $^{13}C/^{12}C$ ratios in marine sediments from the New York Bight. *Estuarine and Coastal Marine Science*. 11:605-611.

Camp, Dresser, McKee, Inc. 1992. *Point-/Nonpoint Source Pollution Loading Assessment. Phase I. Final Report*. Sarasota (FL): Sarasota Bay National Estuary Program.

City of Cape Canaveral. 2001a. *NPDES Monitoring Database 1999-2001*. Permit number FL0020541

__________. 2001b. *Report of aquatic toxicity test results*. Samples of final effluent collected on June 12 and 13 2001. Contact Yvette Manigan.

City of Tampa Bay Study Group, 2001a. *Results of the City of Tampa surface water compliance monitoring program for the year 2000 and examination of long-term water quality and biological indicator trends in Hillsborough Bay*. Submitted to the Florida Department of Environmental Protection Southwest District.

__________.2001b. *Seagrass and Caulerpa monitoring in Hillsborough Bay twelfth annual report.* Submitted to the Florida Department of Environmental Protection Southwest District.

City of Tampa, Florida. 2001. *Howard F. Curren Advanced Wastewater Treatment Plant*. Internet: http://www.tampagov.net/dept_sanitary_sewers/sitemap/plant01.asp.

Codispoti LA. 1989. Phosphorus vs. nitrogen limitations of new and export production. In: *Productivity of the Ocean: Present and Past*. Berger WH, Smetacek V, and Wefer G, eds. New York: Wiley..

Corredor JE, Howarth RW, Twilley RR, and Morrell JM. 1999. Nitrogen cycling and anthropogenic impact in the tropical interamerican seas. *Biogeochemistry*. 46(1/3):163-178. Cited.

Day JW, Hall CA, Kemp WM., and Yanez-Arancibia, A. 1989. *Estuarine Ecology*. Ontario: John Wiley & Sons.

Dugdale RC. 1967. Nutrient limitation in the seas: dynamics, identification, and significance. *Limnology & Oceanography*. 12:685-695.

Ehrhart LM and Redfoot WE. 1995. Composition and status of the marine turtle assemblage of the Indian River Lagoon System. *Bulletin of Marine Science*. 57:279-280.

Englehardt JD, Amy VP, Bloettscher F, Chin DA, Fleming LE, Gokgoz S, Rose JB, Solo-Gabriele H, and Tchobanoglons G. 2001. *Comparative Assessment Of Human And Ecological Impacts Form Municipal Wastewater Disposal Methods In Southeast Florida*. University of Miami. Submitted to the Florida Water Environmental Association Utility Council.

Eppley RW, Renger EH, and Harrison WG. 1979. Nitrate and phytoplankton production in southern California coastal waters. *Limnology and Oceanography*. 24(3): 483-494.

Facemire CF, Gross TS, and Guillette Jr., LJ. 1995. Reproductive Impairment in the Florida Panther: Nature or Nurture? *Environmental Health Perspectives*. 103(Suppl 4):79.

Feacham RG, Bradley DH, Garelick H, and Mara DD. 1983. *Sanitation and Disease Health Aspects of Excreta and Wastewater Management*. New York: Wiley.

Finney BB and Huh CA. 1989. History of metal pollution in the Southern California Bight: an update. *Environmental Science & Technology*. 23:294-303.

Flegal AR, Sanudo-Wilhelmy SA, and Scelfo GM. 1995. Silver in the eastern Atlantic Ocean. *Marine Chemistry*. 49:315-320.

[FDEP] Florida Department of Environmental Protection. 2002a. *Water Reuse: Reuse Statutory Authority.* Internet: http://www.dep.state.fl.us/water/reuse/statauth.htm.

__________. 2002b. *Wastewater Treatment Facilities Reports*. Internet: http://www.dep.state.fl.us/water/wastewater/download.htm.

Forstner U and Wittmann GTW. 1979. *Metal Pollution In The Aquatic Environment*. Berlin: Springer.

Gilmore RG. 1995. Environmental and biogeographic factors influencing icthyofaunal diversity: Indian River Lagoon. *Bulletin of Marine Science*. 57(1):153-170.

Gilmore RG, Donahoe CJ, Cooke DW, and Herema DJ. 1981. *Fishes of the Indian River Lagoon and adjacent waters, Florida*. Technical Report No. 41. Ft. Pierce (FL): Harbor Branch Foundation.

Grossfield S. 2002. Sewage Helps to Kill off Manatees, Biologist Says. *The Boston Globe*. 5 April 2002.

Hazen and Sawyer. 1994. *SEFLOE II Final Report: Broward County Office of Environmental Services North Regional Wastewater Treatment Plant, City of Hollywood Utilities Department Southern Region Wastewater Treatment Plant, Miami-Dade Water and Sewer Department North District Wastewater Treatment Plant, Miami-Dade Water and Sewer Department Central District Wastewater Treatment Plant*. Hollywood (FL): Hazen and Sawyer. Submitted to National Oceanic and Atmospheric Administration.

Hershelman GP, Schafer HA, Jan TK, and Young DR. 1981. Metals in marine sediments near a large California municipal outfall. *Pollution Bulletin*. 12:131-134.

Hoffman BA. and Haddad KD. 1998. General land use and vegetation changes in the Indian River Lagoon System. In: *Indian River Lagoon Estuarine Monograph (Draft)*. Barile DD, ed. Melbourne (FL): Marine Resources Council of East Florida, Florida Institute of Technology.

Howarth RW. 1988. Nutrient limitation of net primary production in marine ecosystems. *Annual Review of Ecology and Systematics*. 19:89-110. Cited.

Howarth RW, Jensen HS, Marino R, and Postma H. 1995. Transport to and processing of phosphorus in near-shore and oceanic waters. In: *Phosphorus in the Global Environment*. Tiessen H, ed. New York: Wiley.

Huh CA, Finney BP, and Stull JK. 1992. Anthropogenic inputs of several heavy metals to nearshore basins off Los Angeles. *Progress & Oceanography*. 30:335-351.

Huntzicker JJ, Friedlander SK, and Davidson CI. 1975. Material balance for automobile-emitted lead in Los Angeles Basin. *Environmental Science Technology*. 9:448-457.

Kapadia A and Swain ED. 1996. *Quantifying Freshwater Discharge for Coastal Hydraulic Control Structures in Easter Dade County, Florida. South Florida Ecosystem Program*. Reston (VA): USGS.

Klein HH and Goldberg ED. 1970. Mercury in the marine environment. *Environmental Science Technology*. 4:765-768.

Larsson DGL, Adolfsson-Erici M, Parkkonen J, Pettersson M, Berg AH, Olsson PE, and Forlin L. 1999. Ethinyloestradiol – An undesired fish contraceptive. *Aquatic Toxicology*. 45: 91-97.

Lietz AC. 2000. Nutrient transport to Biscayne Bay and water-quality trends at selected sites in South Florida. In: *USGS Program on the South Florida Ecosystem: 2000* Proceedings. OFR 00-449. Reston (VA): USGS.

Lipp EK, Farrah SA, and Rose JB. 2001. Assessment and impact of microbial fecal pollution and human enteric pathogens in a coastal community. *Marine Pollution Bulletin*. 42(4): 286-293.

Malone TC, Conley DJ, Fisher TF, Gilbert PM, Harding LW, and Sellner KG. 1996. Scales of nutrient-limited phytoplankton productivity. *Chesapeake Bay. Estuaries*. 19:371-385.

Marella RL. 1999. *Water withdrawals, use, discharge, and trends in Florida, 1995*.USGS Water Resources Investigations Report 99-4002. Talahassee (FL): USGS in cooperationwith the Florida Department of Environmental Protection.

Matthai C and Birch GF. 2000. Trace metals and organochlorines in sediments near a major ocean outfall on a high energy continental margin (Sydney, Australia). *Environmental Pollution*. 110: 411-423.

McPherson BF and Halley R. 1996. *The South Florida Environment – A region under stress*. U.S. Geological Survey Circular, 1134.

McPherson BF, Miller RL, Haag KH, and Bradner A. 2000. *Water quality in Southern Florida, 1996-1998*. U.S. Geological Survey Circular, 1207.

Morel FMM, Westphal JC, O'Melia CR, and Morgan JJ. 1975. Fate of trace metals in Los Angeles County wastewater discharge. *Environmental Science & Technology*. 9:756-761.

Myers VB and Iverson RI. 1981. Phosphorus and nitrogen limited phytoplankton productivity in northeastern Gulf of Mexico coastal estuaries. In: *Estuaries and Nutrients*. Nielson GJ and Cronin LE, eds. New York: Humana Press.

[NOAA] National Oceanic and Atmospheric Administration. 1999. *Florida Bay and Adjacent Marine Systems Science Program Overview*. Internet: http://www.aoml.noaa.gov/flbay.program_overview.html.

National Research Council. 2000. *Clean Coastal Waters: Understanding and Reducing the Effects of Nutrient Pollution*.

Nichols KM, Miles-Richardson SR, Snyder EM, Giesy JP. 1998. Effects of exposure to municipal wastewater in situ on the reproductive physiology of the Fathead Minnow (*Pimephales Promelas)*. *Environmental Toxicology and Chemistry*. 18(9):2001-2012.

Paerl HW. 1997. Coastal eutrophication and harmful algal looms: importance of atmospheric deposition and ground water as "new" nitrogen and other nutrient sources. *Limnology & Oceanography*. 42(5 part 2):1154-1165.

Paul JH, Rose JB, Brown J, Shinn E, Miller S, and Farrah S. 1995. Viral tracer studies indicate contamination of marine waters by sewage disposal practices in Key Largo, Florida. *Applied and Environmental Microbiology*. 61:2230-2234.

Penrose W, Conacher H, Black R, Maranger J, Miles W, Cunningham H, and Squires W. 1977. Implications of Inorganic/Organic Interconversion on Fluxes of Arsenic in Marine Food Webs. *Environmental Health Perspectives*. 19:53-59.

Pritchard D. 1967. Observations of circulation in coastal plain estuaries. In: *Estuaries*. Lauff G, ed. Publication No. 83. Washington (DC): American Association for the Advancement of Science.

Pribble RJ, Janicki AJ, and Greening H. 1999. *Baywide environmental monitoring report 1993-1998*. Technical Report #07-99. Tampa Bay Estuary Program.

Rabalais NN, Turner RE, Justic D, Dortch Q, and Wiseman Jr. WJ. 1999. *Characterization of Hypoxia: Topic , Report for the Integrated Assessment of Hypoxia in the Gulf of Mexico*. NOAA Coastal Ocean Program. Decision Analysis Series No. 15. Silver Spring (MD): NOAA Coastal Ocean Program.

Randazzo AF and Jones DS. 1997. *The Geology of Florida*. Gainesville:University Press of Florida.

Ravizza GE and Bothner MH. 1996. Osmium isotopes and silver as tracers of anthropogenic metals in sediments from Massachusetts and Cape Cod Bays. *Geochimica Cosmochimica Acta*. 60:2753-2763.

Roat P and Alderson M. 1990. *Sarasota Bay Project: State of the Bay Report*. Sarasota (FL): Sarasota Bay National Estuary Program.

Robertson LJ, Campbell AT, and Smith HV. 1992. Survival of *Cryptosporidium parvum* oocysts under various environmental pressures. *Applied and Environmental Microbiology*. 58: 3494-3500.

Rodgers-Gray TP, Jobling S, Morris S, Kelly C, Kirby S, Janbakhsh A, Harries JE, Waldock MJ, Sumpter JP, and Tyler CR. 2000. Long-term temporal charges in the estrogenic composition of treated sewage effluent and its biological effects on fish. *Environmental Science & Technology*. 34(8):1521-1528.

Ryther JH and Dunstan WM. 1971. Nitrogen, phosphorus and eutrophication in the coastal marine environment. *Science*. 171:1008-1112.

Sadik O, and Witt DM. 1999. Monitoring endocrine-disrupting chemicals. *Environmental Science and Technology*. pp. 368A-374A.

Sarasota Bay National Estuary Program. 1993. *Sarasota Bay: Reclaiming paradise: A report to the people from the Sarasota Bay National Estuary Program*.

__________. 2000. *State of the Bay, 2000. Another day in paradise*.

Schindler DW. 1977. Evolution of phosphorus limitation in lakes. *Science*. 195: 260-262.

__________. 1978. Factors regulating phytoplankton production and standing crop in the world's freshwaters. *Limnology and Oceanography*. 23(3): 478-486.

Sellner KG. 1997. Physiology, ecology, and toxic properties of marine cyanobacteria blooms. *Limnology & Oceanography*. 42(5 part 2):1089-1104.

Smith VH. 1982. The nitrogen and phosphorus dependence of algal biomass in lakes: An empirical and theoretical analysis. *Limnology & Oceanography*. 27(6):1101-1112.

Steidinger KA, Roberts BS, Tester PA, Tomas CR, and Vargo GA. 1996. *Red Tide Research Planning And Coordination Meeting Repor: Nov. 6-7*. Department of Environmental Protection, Florida Marine Research Institute.

[US EPA] U.S. Environmental Protection Agency. 2000a. Ambient water quality criteria recommendations, lakes and reservoirs in nutrient ecoregion XIII. EPA 822-B-00-014. Washington (DC): US EPA.

__________.2000b. Ambient water quality criteria recommendations, rivers and streams in nutrient ecoregion XII. EPA 822-B-00-021. Washington (DC): US EPA.

[USGS] U.S. Geological Survey. 1996a. *South Florida Ecosystems: Changes through time*. FS-171-95. Reston (VA): USGS.

__________. 1996b. *Ecosystem history of Florida Bay*. FS-144-96. Reston (VA): USGS.

__________. 1996c. *Ecosystem history : Florida Bay and the Southwest coast*. Internet: http://sofia.usgs.gov/metadata/sflwww/lbwfbay.html.

__________. 2002. *Groundwater Surface Water Interactions and Relation to Water Quality in the Everglades*. Internet: http://sofia.usgs.gov/projects/wtr_flux/

Valette-Silver NJ, Riedel GF, Crecelius EA, Windom H, Smith RG, and Dolvin SS. 1999. Elevated arsenic concentrations in bivalves from the southeast coasts of the USA. *Marine Environmental Research*. 48:311-333.

Woolson E. 1977. Fate of Arsenicals in Different Environmental Substrates. *Environmental Health Perspectives*. 19:73-81.

York DW, Menendez P, and Walker-Coleman L. 2002. *Pathogens in reclaimed water: The Florida experience*. 2002 Water Sources Conference.

Zhou X and Rost JB. 1995. *Phillippi Creek Water Quality Report*. Sarasota (FL): Report to the Sarasota County Commissioners.